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GEOLOGY OF THE MASSIVE SULFIDE DEPOSITS AT IRON MOUNTAIN

SHASTA COUNTY, CALIFORNIA

By A. R. KINKEL, JR., and J. P. ALBERS

Prepared in cooperation with the
United States Geological Survey

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OUTLINE OF REPORT

Illustrations

ABSTRACT

The Iron Mountain mine in the West Shasta copper-zinc dis-rict is in the rugged Klamath Mountains 15 miles northwest of edding, California. The principal ore bodies are large lenses of assive pyrite that contain chalcopyrite and sphalerite and minor mounts of gold and silver.

The oldest rocks in the district are the andesitic flows and yroclastic rocks of the Copley greenstone, which is probably Lower r Middle Devonian in age. They are overlain by flows and pyro-lastics of the Balaklala rhyolite of Middle Devonian age, described y Diller. Submergence during Middle Devonian initiated the depo-ition of shales, tuffs, and limestones of the Kennett and younger ormations. Later the rocks were folded, locally sheared, and intruded y two large plutons.

The massive sulfide deposits of the Iron Mountain mine occur n a porphyritic facies of the Balaklala rhyolite. Tuff and agglom-rate layers appear to have been unfavorable for ore deposition at ron Mountain. The ore bodies are composed almost entirely of ulfide minerals and are in sharp contact with rhyolite. The ore odies range in size from a few thousand tons to more than 5,000,000 ons, but all are faulted parts of an originally continuous ore body hat was 4,500 feet long. All the massive sulfide ore contains some opper and zinc, but minable bodies of copper-zinc ore are closely ssociated with feeder channels along faults that existed prior to ormation of the ore.

The main controls of ore deposition for the district are a ently plunging anticlinorium, favorable layers in the Balaklala hyolite, and a thick cover of shale a few hundred feet above the ore one. The Iron Mountain ore body occurs where a steep feeder hannel cuts folded beds near the crest of a large northeast-trending nticlinorium.

INTRODUCTION

The Iron Mountain mine, which is owned and operated by The Mountain Copper Company, Limited, is located in Shasta County, California, near the eastern edge of the Weaverville quadrangle. It is the southernmost mine in the West Shasta copper-zinc district, which extends 8 miles northeastward from Iron Mountain (fig. 1). The mine is 17 miles by road northwest of Redding and lies at an altitude of 2600 feet in the rugged foothills of the Klamath Mountains at the north end of the Sacramento Valley. A hard-surfaced county road connects the Iron Mountain mine with U. S. Highway 299. The Southern Pacific Railroad passes through Redding, and the ore from the mine is carried to a spur of the railroad by an aerial tramway.

There is little residual soil in the area, but rock mantle masks the geology of many slopes. Good timber is scarce except at the higher altitudes, but a heavy growth of chaparral makes travel difficult over much of the area.

The ore deposits of the Iron Mountain mine were discovered about 1865, but the mining of the massive sulfide deposits for their copper content did not begin until 1897. The development of separate bodies of sulfide ore led to the naming of individual ore bodies as different mines, although they were mined as part of one operation by The Mountain Copper Company, Limited. Thus the Old Mine, Number 8 mine, Hornet mine, etc. are separate, and were worked at different times, but all are part of the Iron Mountain mine.

The more important publications of the many geologists who have worked in Shasta County during the past 50 years are listed in the bibliography at the end of this report. The publications contain conflicting opinions on the origin of some of the rocks, and this divergence emphasizes the need for further study.

This report is based on detailed surface and underground mapping at the Iron Mountain mine done during the summer of 1947. The description of the regional geology is based on 1:24,000-scale mapping by the authors (1945-49) of about 200 square miles in the four 7½-minute quadrangles surrounding the mine, as part of an investigation of the geology of the West Shasta copper-zinc district and the relationship of the mineralization to the rocks and structure of this region. The work is part of a cooperative program between the California Division of Mines and the U. S. Geological Survey.

The interest and cooperation of the staff of The Mountain Copper Company, Limited, have greatly facilitated the mapping of the mine and the compilation of the records of old workings. Special thanks are due to C. W. McClung, general superintendent, T. P. Bagley, mine superintendent, R. K. McCallum, metallurgist of the mine staff, J. M. Basham, consulting engineer, L. T. Kett, general manager, and J. G. Huseby, assistant manager of the company. C. A. Anderson and R. S. Cannon, Jr., of the U. S. Geological Survey spent 10 days in the field with the writers and contributed many valuable

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** Geologist, U. S. Geological Survey.

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REGIONAL GEOLOGY

The rocks in the West Shasta copper-zinc district consist of a thick series of lava flows and pyroclastic rocks that are overlain by sedimentary formations. The Copley greenstone, named by Diller the Copley meta-andesite, consists of mafic flows and pyroclastics of probable Lower or Middle Devonian age, and is the oldest formation exposed in the district. It is here called the Copley greenstone because it is a greenish metamorphosed rock in which the primary ferromagnesian minerals have been altered to chlorite and epidote. Some units show andesitic textures, but other units contain basalt and mafic pyroclastic rocks. The Copley is overlain by silicic flows and pyroclastics of the Balaklala rhyolite of Middle Devonian age. The name "Balaklala rhyolite" proposed by Diller[1] had been abandoned by Graton,[2] but the authors are restoring the name because new evidence indicates that the formation is composed principally of extrusive rhyolite and pyroclastics. A subsidence occurred in Middle Devonian time, as the Balaklala rhyolite is overlain conformably by the Kennett formation which consists of tuff, shale, and limestone and is of Middle Devonian age. Uplift, followed by erosion, removed the Kennett formation from part of the area, but renewed subsidence initiated the deposition of a great thickness of sedimentary material, beginning with the shales, sandstones, and conglomerates of the Bragdon formation of Mississippian age. No sedimentary formations younger than the Bragdon occur in the immediate vicinity of the copper-zinc district, but younger sedimentary rocks overlie the Bragdon east of the district.

The volcanic rocks of the Copley greenstone and Balaklala rhyolite are cut by two masses of intrusive rock, which according to Diller[3] intrude the Mississippian sedimentary rocks and according to Hinds[4] are overlain by Lower Cretaceous strata. The volcanic rocks and the Mississippian sedimentary rocks are folded and locally sheared. The major folds are broad, with moderate dips and low angles of plunge, but in places tight folds are present.

Geologic Formations

Copley Greenstone. The rocks of the Copley greenstone were principally mafic flows and pyroclastics, but also included minor amounts of shale and tuffaceous sediments, as well as a few rhyolitic flows and pyroclastic rocks. Much of the Copley now consists of chlorite-epidote rocks, commonly schistose, in which few primary features remain.[5] As no fossils have been found in the tuffs and shales of the Copley, its age is not definitely known, but its conformable relationship to the overlyin rocks suggests that it is probably of Lower or Midd Devonian age.

Balaklala Rhyolite. The Balaklala rhyolite consist principally of silicic flows interlayered with coarse an fine silicic pyroclastics; about one-fourth of the rhyolit is pyroclastic. Dikes and plugs that were feeders for the extrusive material are included in the Balaklala rhyolite The flows and pyroclastics are abnormally rich in sod and silica. They are light-colored and are commonl porphyritic, with phenocrysts of quartz and plagioclas that range in size from 1 millimeter to 7 millimeters Quartz phenocrysts are the most conspicuous megascopically. The feldspar phenocrysts are altered to sericite and clay minerals and blend with the groundmass Some of the rhyolite is amygdaloidal, and locally it contains flow banding. Coarse rhyolitic pyroclastics and rhyolite tuffs are interbedded with the rhyolite flows, and amygdaloidal andesite is present as thin flows in the lower part of the Balaklala.

Concerning the origin of the Balaklala rhyolite, there has been a major difference of opinion. A resumé of the evidence of the origin is necessary here, because the massive sulfide ore bodies in the West Shasta copper-zinc district are found only in the Balaklala rhyolite, and the distinction between an intrusive and an extrusive origin for this formation has an important bearing on conclusions regarding the geologic structure and the locus of ore bodies.

Diller,[6] on the basis of his work in the Redding and Weaverville quadrangles, recognized the intrusive nature of some of the rhyolite that occurs as dikes and sills but concluded that most of it consists of flows and breccias that formed at the surface by volcanic processes. Graton,[7] on the basis of mapping in the vicinity of the Iron Mountain and Bully Hill mines, concluded that the Balaklala rhyolite is an intrusive, possibly of laccolithic form. Other geologists[8] who worked in the area after Graton followed his interpretation and regarded the Balaklala as intrusive alaskite and alaskite porphyry.

The writers have concluded that Diller was correct in assigning a volcanic origin to the Balaklala rhyolite, and that it consists of rhyolitic flows and pyroclastics, with some intrusive dikes and plugs that probably represent the feeders for the ejected material. The interpretation of the surface origin of much of the Balaklala rhyolite is based on its internal features and on evidence seen at the contacts.

Many types of contact relationships are found between the Balaklala and the underlying Copley rocks, as listed below:

(1) The contact between the Balaklala rhyolite and the Copley greenstone is a normal depositional sequence in many localities. Pyroclastic and ellipsoidal lavas of the Copley are overlain locally by as much as 50 feet of lenticular pyroclastic beds that contain many fragments of porphyritic and nonporphyritic rhyolite in a subordinate matrix of mafic lava. The rhyolite fragments in these pyroclastic beds range from half an inch to several feet in diameter. Some of the fragments have chilled borders.

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[1] Diller, J. S., U. S. Geol. Survey, Geol. Atlas, Redding folio (no. 138), 1906.

[2] Graton, L. C., The copper deposits of Shasta County, California: U. S. Geol. Survey Bull. 430, pp. 71-111, 1909.

[3] Diller, J. S., op. cit., p. 8.

[4] Hinds, N. E. A., Jurassic age of the last granitoid intrusives in the Klamath Mountains, California: Am. Jour. Sci., 5th ser., vol. 27, pp. 182-192, 1934.

[5] Diller, J. S., op. cit., p. 6.
Hinds, N. E. A., Geologic formations of the Redding-Weaverville districts, northern California: California Div. Mines Rept. 29, p. 86, 1933.

[6] Diller, J. S., op. cit., p. 7.

[7] Graton, L. C., op. cit., p. 87.

[8] Hinds, N. E. A., op. cit., 1933.
Averill, C. V., Preliminary report on the economic geology of the Shasta quadrangle: California Div. Mines Rept. 27, pp. 3-65, 1931.
Seager, G. F., Petrology of the Balaklala chonolith, Shasta County, California (abstract): Geol. Soc. America Bull., vol. 50, no. 12, part 2, pp. 1958-1959, 1939.

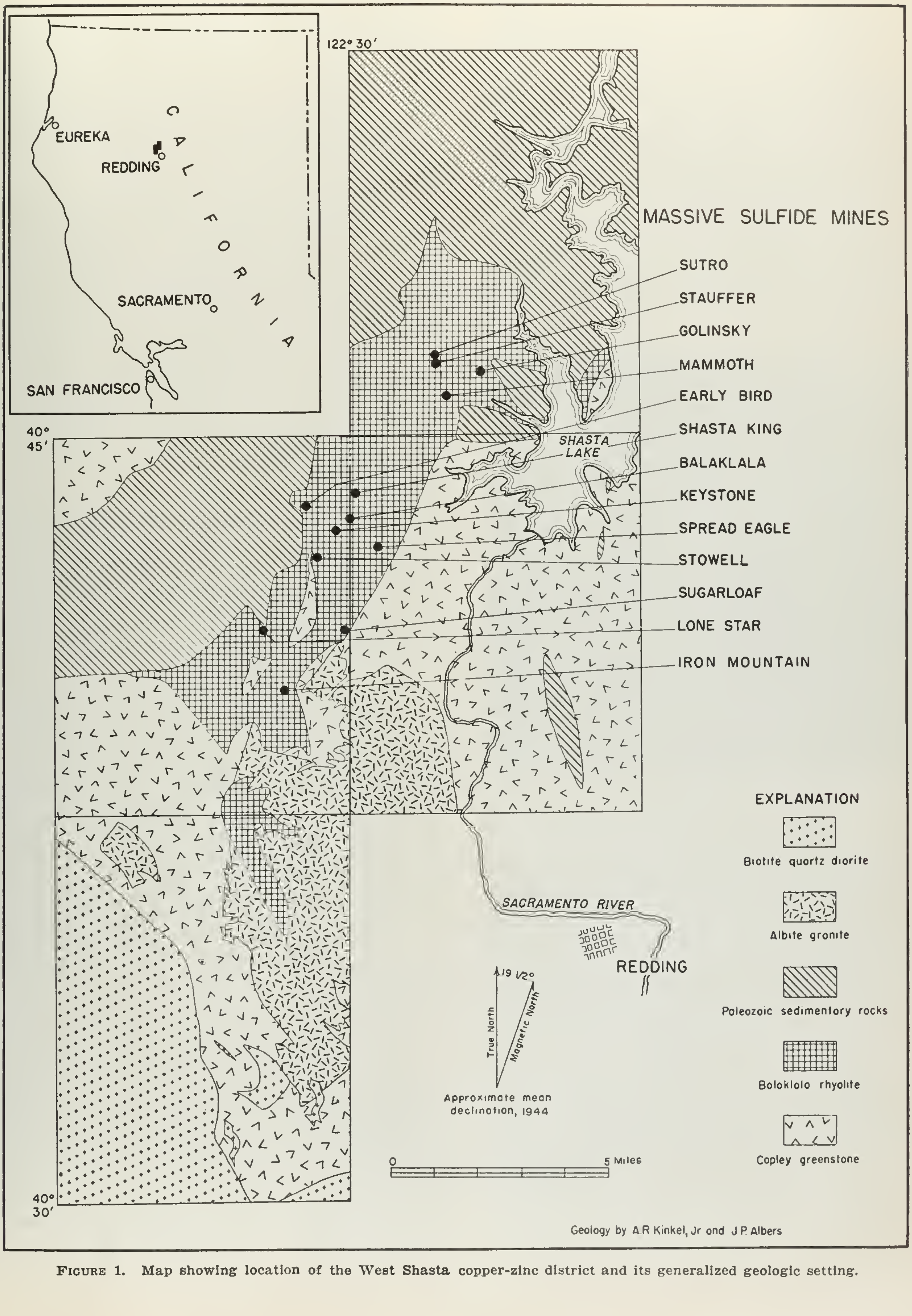

Figure 1. Map showing location of the West Shasta copper-zinc district and its generalized geologic setting.

(2) In other areas near the contact a few rhyolite bombs occur in rocks composed mainly of bombs and fragments of andesitic lava.

(3) The basal layers containing rhyolite bombs and fragments in places grade upward into either porphyritic or nonporphyritic rhyolite; but in other localities they are in sharp contact with overlying rhyolitic rocks.

(4) In some places the Balaklala rhyolite rests on the Copley greenstone with a sharp contact, but thin amygdaloidal flows of andesite similar in appearance to those of the underlying Copley occur in the Balaklala above the main contact. Lenses of volcanic debris composed principally of crystal chips, and fragments of porphyritic rhyolite also occur in the Copley greenstone several hundred feet below the main contact with the Balaklala.

The presence of rhyolitic bombs and minor flows in the upper part of the Copley greenstone, and the occurrence of small mafic flows in the lower part of the Balaklala rhyolite indicate that the change from predominantly mafic to predominantly felsic lavas was not abrupt and that interlayering of the two types of lava was common at the contact.

FIGURE 2. Pyroclastic beds in the Balaklala rhyolite; beds of coarse pyroclastic rock overlain by shaly tuff with pyroclastic layers.

Internal structures also provide evidence of the extrusive nature of the Balaklala rhyolite. At least 20 percent of the Balaklala rhyolite contains either layers of coarse volcanic fragments or bedded tuffaceous material. Evidence of rude sorting in volcanic breccias, graded bedding in the finer layers, the persistence and evenness of bedding in tuffs, the presence of unbroken shaly layers in the tuff, flow banding that parallels the fragmental layers in some of the rhyolite, interlayering of silicic and mafic material, layers of amygdaloidal rhyolite, and fragments of rhyolite in the andesitic flows all point to an effusive origin for much of the Balaklala rhyolite. Many massive structureless outcrops of the Balaklala rhyolite display no internal features that indicate mode of origin.

Conclusive proof of the surface origin of the bedded material in the rhyolite is supplied by the presence of a fossil in a bed of crystal tuff near the top of the Balaklala. This fossil has been determined by Dr. D. H. Dunkle of the National Museum as a fish plate from an euarthrodiran fish close to *Titanichthys* of Middle Devonian age.

A small body of rhyolite porphyry shown in the southeastern part of the Iron Mountain map is believed to occupy one of the feeder channels for the extrusive rocks. Small bodies of intrusive breccia are found near the borders of this rhyolite porphyry plug that are quite different from the breccias of pyroclastic origin. Other steep tabular rhyolite porphyry masses that appear to be sills and dikes intruding the underlying Copley greenstone crop out along the southern part of the map area. Still other bodies of rhyolite intrude the Copley northwest of the mine.

Kennett Formation. The Kennett formation of Middle Devonian age does not occur in the mine area but is exposed northeast of the mine. A description is included in this report because the Kennett formation was deposited on the Balaklala rhyolite and at the contact there is further evidence of the surface origin of the Balaklala rhyolite. In addition, the Kennett is the lowest formation in the thick cover of shale that overlies the mineral district. It is composed predominantly of siliceous black shale but contains tuff and limestone. Diller [9] reports that the formation has a minimum thickness of 865 feet but may have been thicker because much of the Kennett in some areas was removed by erosion before the deposition of the younger sediments.

Evidence that the Kennett formation rests conformably on the Balaklala rhyolite lies in the fact that interbedding of shale, shaly tuff, crystal and lithic tuff, fine pyroclastics, and flow-banded rhyolite is so common between the two formations that it is usually difficult to draw a contact between them. Some rudely bedded sandy debris and arkose, apparently derived from the erosion of Balaklala rocks, occurs locally. At a few places black shale of the Kennett formation lies directly on massive flows of Balaklala rhyolite.

No rhyolite has been found that intrudes the strata of the Kennett formation. Such an occurrence in the lower part of the Kennett is not considered impossible because volcanic activity continued into Kennett time. Pyroclastics and flows of the Balaklala type occur several hundred feet above the base of the Kennett, and feeders for these may have cut the shale underlying the rhyolitic pyroclastic beds and flows. The fish plate, found in rhyolite tuff in the upper part of the Balaklala marks the change from volcanic conditions, in which flows predominated, to primarily marine sedimentation and dates this change as occurring in Middle Devonian time.

The Kennett formation is overlain by a great thickness of Paleozoic sedimentary rocks northwest of the mapped area.

Plutonic Rocks

Two plutons intrude Copley greenstone and Balaklala rhyolite in the West Shasta copper-zinc district south of the Iron Mountain area. The older and smaller of these plutons is albite granite, and it is exposed about $\frac{3}{4}$ mile southeast of Iron Mountain. It crops out as a rudely elliptical stock over 18 square miles of the district. The younger pluton is biotite-quartz diorite, and it is exposed 7 miles southwest of Iron Mountain over an area of 17 square miles in the southwestern corner of the West Shasta district. It extends for many miles to the southeast and to the northwest out of the mapped area.

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[9] Diller, J. S., op. cit., p. 2.

Albite Granite. The albite granite varies considerably in texture and mineralogy at different localities, but it has many resemblances to the Sparta granite in Oregon described by Gilluly.[10]

The albite granite in most places is light colored and has a granitoid texture. Quartz and feldspar grains in the equigranular facies average about 2 millimeters in size, but much of the granite also contains quartz phenocrysts. Combined quartz and plagioclase, in about equal proportions, make up more than 90 percent of the granite and altered ferromagnesian minerals less than 10 percent. The plagioclase now present is all ablite or albite-oligoclase, but saussuritic cores in some crystals suggest that the original feldspar may have been more calcic. Veinlets of quartz and albite replacing the rock, and secondary myrmekite and micrographic intergrowths of quartz and albite show that albitization is widespread in the rock. Much of the feldspar has been replaced by quartz. Although a little relict hornblende is present, the principal ferromagnesian minerals are chlorite and epidote.

The albite granite appears massive and little sheared at most localities, but some deformation has occurred, particularly in parts containing numerous xenoliths of Copley greenstone. At these places the rock is mashed or sheared and has been altered to sericite schist.

The albite granite intrudes the Copley greenstone and the Balaklala rhyolite. It has not been found in contact with the Devonian and younger sedimentary rocks in the area mapped. It transgresses the schistosity of the invaded rocks in many places, but is not itself foliated except in small areas. On the basis of his mapping in the Redding quadrangle, Diller [11] determined its age tentatively as late Jurassic.

Biotite-Quartz Diorite. The larger pluton ranges in composition from diorite to granodiorite. The rock has a granitoid texture, is light gray, and has a fresh appearance. It contains predominantly quartz, biotite, and zoned oligoclase-andesine and has less than 10 percent each of hornblende, orthoclase, and augite.

A planar structure is developed throughout most of the intrusive. This structure is concordant in strike and dip along the margins of the intrusive with its steep contacts and is horizontal in the center of the instrusive, which suggests that the roof of the intrusive mass was only slightly above the present erosion surface.

Biotite-quartz diorite intrudes both the albite granite and the shales of the Bragdon formation of Mississippian age. It is overlain nonconformably by Lower Cretaceous sedimentary rocks and must be late Jurassic in age.[12]

Structure and Geologic History

Rocks older than the Copley greenstone are not exposed in the West Shasta copper-zinc district, but gneiss and schist that are believed to underlie the Copley occur about 15 miles west of the mining district.[13] The Copley greenstone was a lava field that extended over at least 1000 and probably over several thousand square miles.[14] The Balaklala rhyolite was much less extensive, but as much of it has been removed by the present erosion cycle or lies under a cover of younger sediments, its original limits are not accurately known. The silicic volcanic rocks of the Balaklala apparently formed a volcanic highland on the Copley lava field but some mafic flows occur with the silicic flows. The deposition of mafic, Copley-type flows probably continued in adjoining areas during the formation of the highland of Balaklala rocks, as there appears to be an overlapping of Copley and Balaklala rocks near the edges of the highland.

The Copley and Balaklala rocks were submerged in Middle Devonian time and the Kennett formation composed of siliceous shale and tuff with interbedded limestone was deposited upon the volcanic terrain. The Kennett formation is overlain north of the copper-zinc district by shale, sandstone, and conglomerate of the Bragdon formation of Mississippian age. An erosional unconformity occurs between the Kennett and Bragdon formations; part of the Kennett has been eroded. An intrusion of albite granite and a subsequent intrusion of biotite-quartz diorite cut all the rocks in the district. Both intrusions probably occurred in late Jurassic time.

The major structural feature of the Shasta copper-zinc district is a northeast-trending, gently domed anticlinorium that culminates about 5 miles northeast of Iron Mountain. Folding is moderate in the copper-zinc district; the folds range from gentle near the axis of the anticlinorium to close in places along the flanks. The date of the major folding cannot be determined with certainty from the evidence in the Iron Mountain area. The folding occurred after Mississippian time but prior to the deposition of the Chico formation (Upper Cretaceous), and Diller [15] and Hinds [16] give evidence that the main period of folding occurred in late Jurassic time. The rocks are regionally metamorphosed, the mafic lavas being altered to chlorite-epidote rocks and the felsic lavas to sericitic and siliceous rocks. The rocks are commonly schistose, and at least part of the schistosity was formed before the intrusion of the albite granite; they were mineralized and further silicified after the intrusion of the albite granite.

An angular unconformity is present between the older formations and the Chico formation of Upper Cretaceous age that occurs to the south of the mapped area. The Chico strata are tilted to the south at low angles and are overlain by the Tuscan and Tehama formations of Pliocene age, which are composed of interbedded sedimentary and pyroclastic material. The Pleistocene gravels of the Red Bluff formation form a thin veneer on the older formations around the edges of the valleys.

IRON MOUNTAIN MINE

History and Production

The first claims on the large gossan outcrops on Iron Mountain were staked in the early 1860's and held for the future value of the gossan as iron ore. Silver ore was discovered in the gossan in 1879 and some development work

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[10] Gilluly, James, Replacement origin of the albite granite near Sparta, Oregon: U. S. Geol. Survey, Prof. Paper 175-C, pp. 67-81, 1933.

[11] Diller, J. S., op. cit., p. 8.

[12] Hinds, N. E. A., op. cit., 1934.

[13] Hinds, N. E. A., op. cit., p. 81, 1933.

[14] Diller, J. S., op. cit., p. 7.
Hinds, N. E. A., op. cit., p. 86, 1933.
Ferguson, H. G., Gold lodes of the Weaverville quadrangle, California: U. S. Geol. Survey Bull. 540, pp. 22-79, 1912.
Averill, C. V., op. cit., p. 15, 1931.

[15] Diller, J. S., op. cit., p. 10.

[16] Hinds. N. E. A., op. cit. ,1934.

FIGURE 3. Iron Mountain mine. Richmond mine plant.

and mining were done in the silver-rich portions. At that time little interest was shown in the disseminated chalcopyrite and the massive sulfide ores that were encountered in the search for precious metals. It was not until 1895, when a thorough prospecting of Iron Mountain disclosed large bodies of copper-bearing sulfides, that the mineral possibilities of the region now known as the West Shasta copper-zinc district were recognized.

Silver ores were mined intermittently in the gossan at Iron Mountain from 1879 to 1897, when the present owners, The Mountain Copper Company, Limited (formerly Mountain Mines Company) began mining the massive sufide ores for their copper content. The Old Mine ore body (pl. 2) was the first massive sulfide ore to be mined. It averaged 7.5 percent copper, 1.0 ounce of silver, and 0.04 ounce of gold to the ton, but the ore of the Old Mine ore body was enriched by secondary copper minerals. The zinc content of this ore body is reported by the mine staff to have been more than 2 percent, and may have been as much as 5 percent. The total production from the Old Mine sulfide lens was 1,608,000 tons of massive sulfide ore.

In 1907 a zone of disseminated chalcopyrite was found to underlie the Old Mine sulfide lens. Eight hundred and twenty thousand tons of ore containing 3.5 percent copper, 0.001 ounce of gold, and 0.04 ounce of silver was produced from this disseminated chalcopyrite zone (the Number 8 mine). The zinc content of the disseminated copper ore is not known with certainty, but it is reported by the mine staff to have been very low.

Copper-zinc ore has been mined from the Richmond and the Mattie ore bodies, and minor copper-bearing sulfides occurred along the borders of the Hornet ore body. The flotation plant that treated the ore from the Richmond ore body is located near the portal of the Richmond adit. About 380,000 tons of ore was mined from the Richmond and Mattie ore bodies. This ore contained 2.0 percent copper and 3.5 percent zinc. The Brick Flat ore body containing copper-zinc ore has not been mined. Massive pyrite containing very little copper and zinc has been mined in large quantities from the Hornet and Richmond ore bodies, and a large tonnage of pyrite still remains available for mining in the Richmond, Complex, and Brick Flat ore bodies. Three million six hundred thousand ton of pyrite has been mined at Iron Mountain; this ore i used in the production of sulfuric acid.

Copper has been produced by The Mountain Coppe Company, Limited, from direct smelting ore, from sulfid ore treated in a flotation plant, and from the leaching o pyritic ore that was mined for its sulfur content. Th Iron Mountain mine produced 197,951,738 pounds of copper to the end of 1919 from direct smelting ore, but figures are not available for the total copper production since that date as copper production was reported only by counties. After 1919, the principal periods of copper production from ore from Iron Mountain were in 1925, 1928-1930, and 1943-1947. Minor copper production was maintained between these years by leaching of ore that was mined for the production of sulfur. No record is available on the production of zinc from the Iron Mountain mine.

Gold and silver have been extracted from the gossan overlying the massive sulfide ore of the Old Mine ore body. From 1889-1893, 38,000 tons of gossan was mined that contained 8 ounces of silver to the ton. The gold content of this ore is not known. From 1929 to 1942, 2,600,000 tons of gossan was mined that contained 8.3 ounces of silver and 0.073 ounce of gold per ton.

Only small portions of the Iron Mountain mine have been accessible at any one time, and this has handicapped all geologists who have studied the ore bodies. An attempt is made in this report to record the information available on the location and mineralogy of the ore bodies mined many years ago, but it is recognized that many of the data are incomplete and fragmentary. The underground workings that were accessible at the time of the writers' study were the Richmond haulage level (2600-foot level), the grizzly floor under the northeast end of the Richmond ore body (2650-foot level), and the 2700-foot level. The levels of the Iron Mountain mine are numbered according to their elevation above sea level and are shown on plate 3. The Richmond Extension stopes at the southwest end of the Richmond ore body and some drifts and raises in the Complex ore body were also accessible. Diamond drill cores from the Brick Flat ore body were examined. Information on the Hornet, Old Mine, Number 8 mine, Confidence-Complex, New Camden, and Mattie ore bodies was obtained by a compilation of old and incomplete mine maps. Much information on the old workings was lost when a flood destroyed the engineering office at the mine in 1933.

Formations in the Mine Area

The Copley greenstone, the Balaklala rhyolite, and the albite granite are the only rock units that occur in the immediate vicinity of the Iron Mountain mine. These are shown on the surface map and on the cross sections (pls. 1 and 4). The writers have found that individual flows of porphyritic rhyolite of the Balaklala are characterized by approximate uniformity of phenocryst size. The stratigraphy within the Balaklala is mapped on such distinctive flows and on pyroclastic beds. For this reason, the porphyritic rhyolites in the Iron Mountain area are subdivided as shown in the explanation of plate 1. Even though it is recognized that a rigid classification based on phenocryst sizes cannot be maintained everywhere because of some heterogeneity within flows, the writers lieve that the method of distinguishing individual flows phenocryst size is valid in the West Shasta copper-zinc strict. A change in phenocryst size can be correlated ith other criteria used for distinguishing separate flows.

Much of the rock in the mine area has been sheared, licified, chloritized, and argillically altered, making the istinction between rock types very difficult.

Ore Deposits

haracter and Distribution

The two types of ore in the Iron Mountain mine are massive pyrite bodies that contain chalcopyrite and spha- rite and zones of disseminated chalcopyrite and quartz-halcopyrite veins in schistose rock. The massive sulfide re is much more abundant than the disseminated ore. Disseminated ore occurs only in the Number 8 mine and he adjoining Confidence-Complex ore bodies. All other ore bodies in the Iron Mountain mine are of the massive ulfide type.

The massive sulfide ore bodies differ in shape and attitude. The Hornet ore body is nearly vertical. The Mattie is a cigar-shaped, horizontal ore body whose faulted extension has not been located; it may have been removed by erosion. The rounded bottom of the erosion remnant of the Old Mine ore body suggests that a large gently dipping lens-shaped or synclinal mass was once present. The Richmond and Complex ore bodies, taken together, have a synclinal shape, and the Brick Flat ore body also may be in part synclinal, although its shape is determined only by rather widely spaced drill holes. The Number 8 mine ore bodies and the Confidence-Complex ore bodies (figs. 5 and 6) are in zones of chalcopyrite-bearing sericitic, porphyritic rhyolite and along quartz-chalcopyrite veins on minor faults.

Probably Iron Mountain contained about 25,000,000 ons of massive sulfide ore before the erosion of the upper portion of the Old Mine ore body.

Minerals of the Primary Ore

The principal ore minerals are pyrite, chalcopyrite, and sphalerite. The ore contains recoverable amounts of gold and silver. Galena has been seen in a few specimens and tennantite-tetrahedrite has been reported by the mine taff. Magnetite was not seen in the main ore bodies, but mall deposits composed of magnetite and specular hema- ite are closely associated with the ore bodies. The magnetite and hematite replace porphyritic rhyolite, but the ignificance of the presence of small bodies of these minerals near the bodies of massive pyrite is not known. The only gangue minerals seen in the ores are very small amounts of quartz and calcite, both of which occur as nterstitial grains in the sulfide ore and as veinlets cut- ing the ore.

Most of the massive sulfide ores contain 90 to 95 percent pyrite; the silica content is remarkably low, the Hornet ore body containing the least. Assays of 15 diamond drill holes in the main Hornet ore body that repre- ent 1400 feet drilled through massive sulfide ore averaged 2.68 percent silica and 48.6 percent sulfur. The Richmond ore body averaged about 5 percent silica. Small unreplaced or partly replaced ribs of porphyritic rhyolite are found locally in the ore, but hydrothermal alteration and movement have usually transformed these into sericitic or clayey gouges. Polished sections of the ore have not been studied by the writers, but the age relationships of most of the minerals have been determined megascopically in the underground exposures.

Pyrite. Pyrite is the predominant metallic mineral of the ore bodies of the Iron Mountain mine. The grain size ranges from less than 0.5 millimeter to 5 millimeters. A few crystals or clusters of coarse crystals attain a diameter of 1 centimeter. Typical ore is usually a fine-grained, yellow, metallic-looking mass of 1-millimeter pyrite grains containing a few irregular clumps, several inches in diameter, of more coarsely crystalline pyrite. Some euhedral pyrite is present, particularly in the coarse-grained varieties and in parts of the ore that contain unreplaced host rock, but most of the pyrite is anhedral.

Pyrite specimens from different ore bodies differ somewhat in appearance, but the variation is no greater than that found locally in an individual ore body. Ore from the Hornet, Old Mine, and Complex ore bodies is somewhat finer grained than that from the Richmond and Brick Flat bodies. Banded ore occurred along the northwest wall of the Mattie and the southeast wall of the Hornet ore bodies, and banded ore is found locally on the southeast wall of the Complex ore body. Such minor variations, however, only serve to emphasize the uniform character of the enormous masses of pyrite in the ore zone.

Chalcopyrite. Chalcopyrite occurs throughout the pyrite bodies of the mine, but only locally is it present in sufficient quantities to be ore. Bodies of massive pyrite, mined for their sulfur content, contain only 0.5 to 1 percent of copper in chalcopyrite disseminations and veinlets. The copper ore is comprised of the chalcopyrite-rich portions of the massive pyrite bodies. The ore has a more yellowish tint than the pyrite and contains irregular veinlets and small lenses of chalcopyrite, which can be seen only in the high-grade portions of the copper-bearing massive sulfides. In some ore the veinlets and lenticles of chalcopyrite are alined, and this imparts a banded or streaked appearance, but most of the copper ore shows no layering. Chalcopyrite ore in the Number 8 and Confidence-Complex ore bodies is not associated with massive pyrite. In these ores bodies chalcopyrite occurs as disseminations in schistose porphyritic rhyolite, as replacement bodies along faults, and as quartz-chalcopyrite veins along faults. Chalcopyrite is generally more abundant than pyrite in the disseminated copper ore.

Chalcopyrite also occurs in quartz veins that fill fractures in the massive pyrite bodies. These veins vary in composition from quartz with a few specks of chalcopyrite, to chalcopyrite veins with a little quartz. They are rarely more than a few inches in width, and they cut the massive pyrite and silicified wall rocks.

The disseminated chalcopyrite and the quartz-chalcopyrite veins are younger than the massive pyrite ore bodies, and it is probable that the main part of the chalcopyrite was introduced into the massive pyrite bodies at the time the quartz-chalcopyrite veins were formed in the massive sulfide ore and the disseminated chalcopyrite of the Number 8 mine was deposited.

Sphalerite. Sphalerite occurs throughout the pyrite ore, but it is difficult to recognize in hand specimens except in high-grade zinc ore. It was seen in some of the ore at the southwest end of the Richmond ore body, and it is reported by the mine staff to have been abundant in parts of the Mattie ore body and to have occurred locally in the Old Mine ore body.

The sphalerite is a fine-grained, dark gray to black variety, and contains a considerable amount of iron. It tends to be alined in layers and streaks, and where much is present as disseminations it imparts a gray color to the massive pyrite. Veinlets of sphalerite cut the massive pyrite locally, and chalcopyrite-sphalerite veinlets have been seen. The association of chalcopyrite and sphalerite suggests that the two minerals are probably in part contemporaneous, although the mine staff reports that little or no sphalerite occurred with the disseminated chalcopyrite in the Number 8 mine. The sphalerite may have been deposited during a shorter period of time than the chalcopyrite.

Gold and Silver. No silver minerals or gold have been seen in the ore. Tennantite (or tetrahedrite) is reported to have occurred in the Old Mine ore body and may account for the silver content of the ore. Gold and silver occur in massive sulfide bodies and in gossan derived from massive sulfide ore; almost none is found in the disseminated copper ore or in the quartz-chalcopyrite veins.

Quartz. The silica reported in assays of the Iron Mountain ore is almost entirely in the form of quartz. A little sericite is present in the ore, and a very small amount of unreplaced wall rock can be found locally near the ore boundaries and as gouge material in the ore, but silicates other than quartz in the ore probably amount to less than 1 percent of the insoluble material.

Most of the quartz in the massive sulfide ore occurs as individual grains, as films between pyrite grains, or as small irregular bodies of mixed pyrite and quartz. A few quartz and quartz-calcite veinlets occur in massive pyrite ore, but these veinlets seldom exceed a few inches in width and several feet in length. The average silica content of the various massive sulfide ore bodies apparently ranges between 2.5 percent and 5 percent. The disseminated copper vein systems in the Number 8 mine contained much silica, however, in the form of quartz veinlets and silicified wall rock, and constituted a siliceous copper ore.

The quartz in the ore is both pre- and post-pyrite in age. Some of the quartz grains in the ore are unreplaced quartz phenocrysts from the porphyritic rhyolite. Other quartz-rich areas represent partly replaced silicified rhyolite. Some quartz may have been deposited with the massive sulfide bodies, but these bodies were also cut by quartz veins.

Calcite. Calcite is the youngest of the hypogene minerals. It occurs in small amounts with quartz in veins, or less abundantly as small veinlets and irregular patches.

Distribution of Metals

The mineral content of the disseminated ore differs from that of the massive sulfide ore. The disseminated ore contains only pyrite and chalcopyrite in sericitic and siliceous rocks, and contains many chalcopyrite-bearing quartz veins. Pyrite is generally about equal in amount to chalcopyrite. Practically no sphalerite, gold, or silver occur in the disseminated ore. The massive sulfide ore is composed almost entirely of pyrite, but contains cha copyrite and sphalerite in small amounts distribute throughout the massive sulfide bodies, and local conce trations of these minerals occur. Gold and silver occu only in the massive sulfide ore bodies.

The distribution of copper and zinc in the massi sulfide ore is not well known in detail. However, as all t larger concentrations of these metals were mined as bas metal ore, the location of stopes that were mined for t copper and zinc content of the ore shows the location these concentrations. The record is incomplete, as sma bodies of base-metal ore have been encountered at som localities in the mine where such ore could not be mine separately from the massive pyrite.

The copper-zinc ore is found principally along th edges and bottoms of thick sulfide bodies, but it is no everywhere present along such boundaries and locall occurs in minable quantities throughout thinner or bodies. The known concentrations of copper and zinc i the massive sulfide ore at Iron Mountain are as follows:

(1) Two-thirds of the Mattie ore body was mined for coppe and zinc ore, although some bodies of pyrite low in copper and zin were left in place. The average ore mined from the Mattie containe 2.25 percent copper and 3.5 percent zinc.

(2) Small concentrations of copper ore occurred at the bottom and at the top of the Hornet ore body, but these were no mined separately. The Hornet ore body averaged only 0.85 percen copper.

(3) The northeast corner of the Complex ore body, near th Scott fault, contained copper-zinc ore, and small bodies were mine for those metals. The lowest portion of this part of the ore bod contained the highest-grade ore.

(4) Copper-zinc ore occurred along the bottom and west wal of the Complex ore body on the 2600-foot level.

(5) The upper part of the Complex ore body, where it is cu by mine workings on the 3000-foot level, contains an appreciabl amount of copper but has not been mined.

(6) The entire west end of the Richmond ore body, called th Richmond Extension, has been mined for copper and zinc. It was the largest body of base-metal ore in the mine.

(7) A large block of copper-zinc ore occurs in the Brick Fla massive sulfide body. The lower part of the eastern half of the or body is reported to contain the best grade of ore. This ore has not been mined. No oxidation or secondary enrichment has occurred even though the top of this ore body is only 150 feet below the surface and the ore lies above the water table.

(8) The Old Mine ore body is an erosion remnant and probably represents the bottom of a much larger ore body. The Old Mine ore body contained the highest-grade copper ore yet found at Iron Mountain because the sulfides below the leached outcrop were enriched by secondary copper minerals.

Disseminated Copper Ore

A body of disseminated chalcopyrite and pyrite underlies the Old Mine ore body. Where the disseminated ore lies beneath the Old Mine it was mined through the workings of the Number 8 mine, but its extension to the northeast of the Old Mine is known as the Confidence-Complex vein system. The location of this disseminated and vein-type copper ore is shown in plate 2. Information on the distribution of copper and the types of mineralization in the Number 8 and Confidence-Complex workings was obtained from the mine staff and from unpublished reports by G. F. Seager and O. H. Hershey. This section of the mine was closed down and partly filled in 1919, but portions of it were reopened for a short period in 1929-30.

Two principal types of ore that may occur together or separately are present in the Number 8 mine. One type consists of chalcopyrite grains, veinlets, and fairly solid masses of coalesced chalcopyrite veinlets that replaced chistose porphyritic rhyolite. Pyrite is subordinate in mount to chalcopyrite and occurs as scattered anhedral rains. According to Seager[17] the pyrite is the earliest etallic mineral, and is veined by chalcopyrite, quartz, nd chlorite. Many small and discontinuous faults and ouge zones are present, and the largest ore bodies occur t intersections of these gouge zones or fracture zones. The second ore type, quartz-chalcopyrite veins, is less bundant but locally occurs in the disseminated ore.

The quartz-chalcopyrite veins of the Confidence-Complex vein system (the northeasterly continuation of he Number 8 mine ore) occur as fracture fillings. In he southwestern end of the Confidence-Complex workings the ore zone contains both disseminated chalcopyrite and quartz-chalcopyrite veins. The northeastern end of he Confidence-Complex workings contains principally quartz-chalcopyrite veins along a fault that has formed several inches to several feet of gouge. The only exposure of these veins seen by the writers is in the Complex adit on the 3000-foot level. There the vein is exposed for 80 feet and lies under a 1-foot fault gouge. The footwall of the vein is sharp and the wall rock is not replaced. One end of the exposed portion of the vein contains only quartz and chalcopyrite, but the other end consists of 2 feet of massive pyrite containing some chalcopyrite but no quartz. The pyrite ore in the vein is similar in appearance to that in the large massive sulfide ore bodies. There is apparently a gradation at this locality from quartz-chalcopyrite veins to massive pyrite ore along the strike of a single vein.

The rocks adjoining the chalcopyrite ore bodies in the Number 8 mine contain secondary quartz, sericite, chlorite, and disseminated pyrite, but these minerals are more widely distributed than the chalcopyrite.

Structural Features of the Ore Bodies

Form. The massive sulfide deposits, which make up the bulk of the ore of the Iron Mountain mine, are enormous masses composed almost entirely of pyrite replacing porphyritic rhyolite. Except in the vicinity of the Old Mine ore body, the wall rocks are virtually unmineralized.

The Hornet, Richmond, Complex, and Brick Flat massive sulfide ore bodies were one continuous body before they were displaced by the Scott and Camden faults. It also seems possible that the New Camden ore body is a faulted segment of the Complex ore body, but the relationship of these two ore bodies is not well known. The longitudinal section, plate 2, suggests that the ore in the gossan area, which occurs up-dip from the Old Mine ore body and the Number 8 mine ore body, is a faulted portion of the Brick Flat ore body. It therefore seems probable that all the major ore bodies were one continuous deposit before post-mineral faulting. Isolated ore lenses, such as the Mattie and Okosh, which lie along the side of the main ore run, also occur but are small.

Plate 6 is a reconstruction showing the probable shape of the massive sulfide ore body before faulting and erosion had destroyed its continuity. Dip-slip movement was assumed on faults to fit the ore bodies together and the lens-shaped habit of the ore bodies was assumed in estimating the amount of ore removed by erosion.

In the vicinity of the Old Mine ore body, the ore zone occupied a considerable thickness of rock. The Number 8 mine ore was separated vertically from the Old Mine massive sulfide lens and from the sulfide gossan by as much as 300 feet of barren or slightly pyritized rock. The bands of pyritized rock and gossan are irregular in plan as shown on the surface map. The relation between the Old Mine ore and the Number 8 mine ore is illustrated in section B-B′, figure 6, but north of this section, the gossan derived from massive sulfide ore occurs between the level of the Old Mine ore and the level of the Number 8 mine ore. The total thickness of the mineralized zone in the vicinity of the Old Mine ore body is at least 600 feet, measured normal to the bottom of the Number 8 mine ore body.

The mineralized zone, before faulting, lay on a gentle slope rising from the deepest ore in the Number 8 mine northward to a point above the present erosion surface east of Iron Mountain peak. From this point the Brick Flat and Richmond Complex ore bodies occupied a synclinal trough plunging gently northeast. Continuing northeastward through the Hornet ore body, the ore lies steeply along a fault zone. The total length of the original ore body before faulting must have been at least 4500 feet.

The shapes of the Number 8 mine ore bodies are shown in figures 5 and 6. The ore in the Number 8 mine occurred along shear zones, particularly along intersecting shear zones or intersecting minor faults. The ore bodies are reported by the mine staff to parallel the schistosity of the replaced rock. Figure 5, which was compiled from stope plans, shows the shapes of the mined ore bodies. The material between ore bodies was in places mineralized rock that contained too little copper to be mined. Consequently, the plan shows the major ore runs but not the extent of mineralization.

There are two main ore bodies in the Number 8 mine, and each is arcuate in horizontal section. This curvature of the ore bodies is best shown on the 2350-foot level in the east ore run and on the 2500- and 2610-foot levels in the west ore run (fig. 5). Sections A-A′ and B-B′ (fig. 6) illustrate the en echelon pattern of individual ore shoots and indicate that the thickest portions of most of the ore bodies correspond to marked changes in dip.

Relation of Massive Sulfide Ore Bodies to Structures in the Host Rock. The ore deposits in the West Shasta copper-zinc district are found only in the Balaklala rhyolite, but within this formation their distribution is controlled mainly by folds and pre-mineral faults in the rocks, and to a lesser degree by the sheeting and schistosity of the rocks. The relationship between schistosity and folding throughout the region is not that of axial-plane cleavage, and many areas of folded schistosity are found. In general, schistosity is parallel to bedding at Iron Mountain, but schistosity is known to transgress bedding locally, and it is difficult to be certain of the relationship between bedding and schistosity in some areas. Schistosity is strongly developed only in small zones, the majority of the rocks being sheeted or slightly foliated. In strongly schistose areas, evidence of bedding is lacking and the relationship between bedding and schistosity is not known. Areas of regular schistosity are common, but in other areas folds in the schistosity do not have parallel axial planes and may plunge in any direction. The folding appears to be controlled at many places by difference in

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[17] Unpublished report.

competence of beds and by buttressing effects rather than by a regional pattern.

The schistosity north of the Old Mine ore body appears to parallel the Copley greenstone and Balaklala rhyolite contact and the pyroclastic beds of the Balaklala, although in places the parallelism may be due to shearing of beds into lenses in line with the schistosity. Little schistosity is developed in the vicinity of the Richmond-Complex ore body, except near the ore contacts. (The Richmond is the flat portion of the ore body northwest of the "J" fault; the Complex is the steep portion southeast of the "J" fault.) In underground workings near this ore body the schistosity parallels bedding, where the bedding is known, but its alinement may be at variance with the schistosity at the surface. The block of ground between the ore bodies and the surface is not accessible from mine workings.

The relationship between the ore bodies and the schistosity of the rocks in the vicinity of the ore bodies is not well understood. Schistosity and sheeting near the massive sulfide contacts is always parallel to the contact, and at no place does the ore contact cut across schistosity. The massive sulfide shows no tendency to finger into schistose rocks along the schistosity except in a very few minor occurrences at the ends of small ore bodies. The schistosity around the massive sulfide lenses, being parallel to the ore contact, commonly does not parallel the regional schistosity. On the other hand, zones of disseminated pyrite that parallel the ore bodies and chalcopyrite zones in the Number 8 mine are replacements of schistose rocks along the planes of schistosity. The sulfides show no evidence of crushing or rounding and were obviously deposited in a schistose rock, with the schistosity controlling the direction of travel of the sulfide-bearing solution.

The relationship between massive sulfide ore and the schistosity can be explained either as replacement by a massive sulfide body of a crumpled zone in the schistosity or by continued (or renewed) movement in the enclosing rocks after the massive sulfide body was formed. The writers favor the latter explanation because of the gouge and more schistose and sheeted rocks at the ore contact, the lack of similar crumpled zones in the rocks away from ore bodies, the massive, unlayered character of the massive sulfide, and the absence of halos of pyritized rock adjoining the massive sulfide bodies. The rocks were probably somewhat schistose and contained gouge zones at the time the sulfides were introduced, but movement either continued after sulfide deposition, or a later period of movement occurred, in which the massive sulfide bodies acted as a buttress and schistosity formed parallel to the ore contacts.

Ore contacts can be observed in relatively few places because of the mining practice of leaving a 10- to 20-foot "curtain" of massive sulfide between the stopes and the wall rocks. The wall rocks adjoining the ore cave badly when they are encountered in large underground workings, and information on contacts can be obtained only in caved areas, or where the walls were encountered in exploration and development workings. The footwall of the ore is exposed in a few stopes in the west end of the Richmond ore body.

The contact between massive sulfide ore and the enclosing porphyritic rhyolite or nonporphyritic rhyolite is usually abrupt, although some contacts showing repl ment have been found. At most localities no visible cha can be seen in the massive sulfide ore as the contac approached, and the contact has massive sulfide on side, and unmineralized soft, white claylike gouge on other. This gouge is commonly more than a foot thick, it grades from structureless white gouge against the to strongly sheared, sericitized, porphyritic rhyolite the more solid wall rock is approached. It consists highly sheared, altered, porphyritic rhyolite. Rel quartz phenocrysts can be found in the claylike portion the gouge. Some gouge occurs along all observed contac even though its thickness may be less than an inch.

The gouge along the contact locally contains so pyrite in the footwall of the Richmond ore body. In the places, the gouge contains less clay and is a strong sheared sericite schist. The pyrite occurs in rude layers small euhedral pyrite grains that show no evidence crushing. A narrow clay gouge separates the massi pyrite from the sheared, pyritized wall rock. The bands disseminated pyrite in the gouge and sericite schist para lel the ore contact and extend several feet into the foo wall, diminishing in pyrite with distance from the or The mineralized layers have hazy boundaries and are replacement of schistose material parallel to the contac A few quartz veinlets or irregular bodies of more siliceou material may also parallel the ore contact, but no chalco pyrite has been found in these zones. It should be empha sized, however, that along most ore contacts the wall roc is not mineralized.

In a few localities, massive sulfide ore fingers int sericite schist along planes of schistosity. In these places, 1 foot to 2 feet of schist adjoining the ore body may contain irregular bodies of pyrite a few inches to a few feet long, having hazy, gradational boundaries. A main gouge is always present at the outer edge of this mineralized zone. Such contacts are regarded as incomplete replacement along a gouge wall. It is probable that contacts of this type were more common before minor movements along the walls of the ore bodies obliterated them.

The normally sharp contacts between the massive sulfide ore and the wall rock result from two causes. Most of the sharp contacts are believed to be the result of complete replacement of the rock by sulfide against a gouge wall that acted as a guide or barrier to solutions. A few sharp contacts are due to major or minor post-mineral movement, localized in the hydrothermally altered zone at the ore contact, which has destroyed or displaced any halos of disseminated pyrite that may have been present originally.

Bodies of partly pyritized rock, in which much silicified rock remains between the bands of disseminated pyrite, occur outside of the main ore runs. Small stringers and lenses of massive pyrite may occur in such pyritized zones, but they are not bounded by strong gouge walls and usually fade into slightly mineralized rock in a very irregular manner.

Specimens of ore from the Iron Mountain mine that contained streaks of chalcopyrite and sphalerite were seen on dumps, but none was found in place. Members of the mine staff report that the southeast wall of the Hornet ore body and the northwest wall of the Mattie ore body contained a little layered ore, but practically all the ore at

Figure 4. Gossan quarry over the Old Mine ore body.

n Mountain is massive. Ore with a banded appearance, haps derived from the replacement of schistose rocks, eported from other mines of the district.

Post-Mineral Faults. Movement has occurred at or close to the contact of all the massive sulfide ore ies. It is not possible to determine how much of the ge along the ore contacts is pre-mineral in origin, hav- acted as a guide for sulfide replacement, and how h is due to post-mineral movement. At many places sive sulfide ore is slickensided—on slips within ore ies, on walls against contact gouge zones, and on frag- ts of sulfide within the gouge zones. Only those gouges contain crushed sulfide grains and broken or slick- ded fragments of massive sulfide ore are described er the heading of post-mineral faults. All the faults are known to offset ore bodies contain crushed sulfides.

The major post-mineral faults in the mine are the t, the Camden, and the "J" faults. The Camden is a post-mineral and pre-mineral fault.

The Scott fault is curved in strike and dip. The fault ace was seen only on the 2600-foot level, but the record s location in inaccessible workings is fairly complete. unquestionably a post-mineral fault as it offsets the bodies and contains much crushed sulfide ore and frag- ts of slickensided sulfides. The fault zone, where it be observed, is 3 to 5 feet in width and contains many stamosing slickensides and much dark gray to white gouge. However, it is reported to be less than a foot thick at a few localities at the end of the Hornet ore body. The Scott fault is a normal fault that dips approximately 50° to the northeast. The fault flattens along the lower part of the Hornet ore body. It has dropped the Hornet ore body 250 feet below the corresponding section of the Richmond-Complex ore body. The movement on the Scott fault was essentially dip-slip. It should be pointed out that the northeast end of the Richmond-Complex ore body does not appear to match well with the southwest end of the Hornet ore body across the Scott fault. It seems most probable that this is due to lack of accurate information on the shape of the Hornet ore body near the fault but it is possible that subsidiary faults, caused by the movements along a dish-shaped fault surface, occur in the hanging wall of the Scott fault. Flat-dipping faults have also been reported along the top of the Hornet ore body and over the northeast part of the Complex ore body near the Scott fault, but information on these faults is fragmentary.

The Camden fault can be seen in many places in the underground workings. In most of these exposures it consists of 1 foot to 5 feet of gouge and sheared rock containing crushed sulfides, but the fault zone is at least 50 feet wide where it is exposed at the west end of the 2600-foot level. The fault forms the southeast wall of the Complex ore body and turns to form the south end of the Richmond ore body, which is the offset portion of the

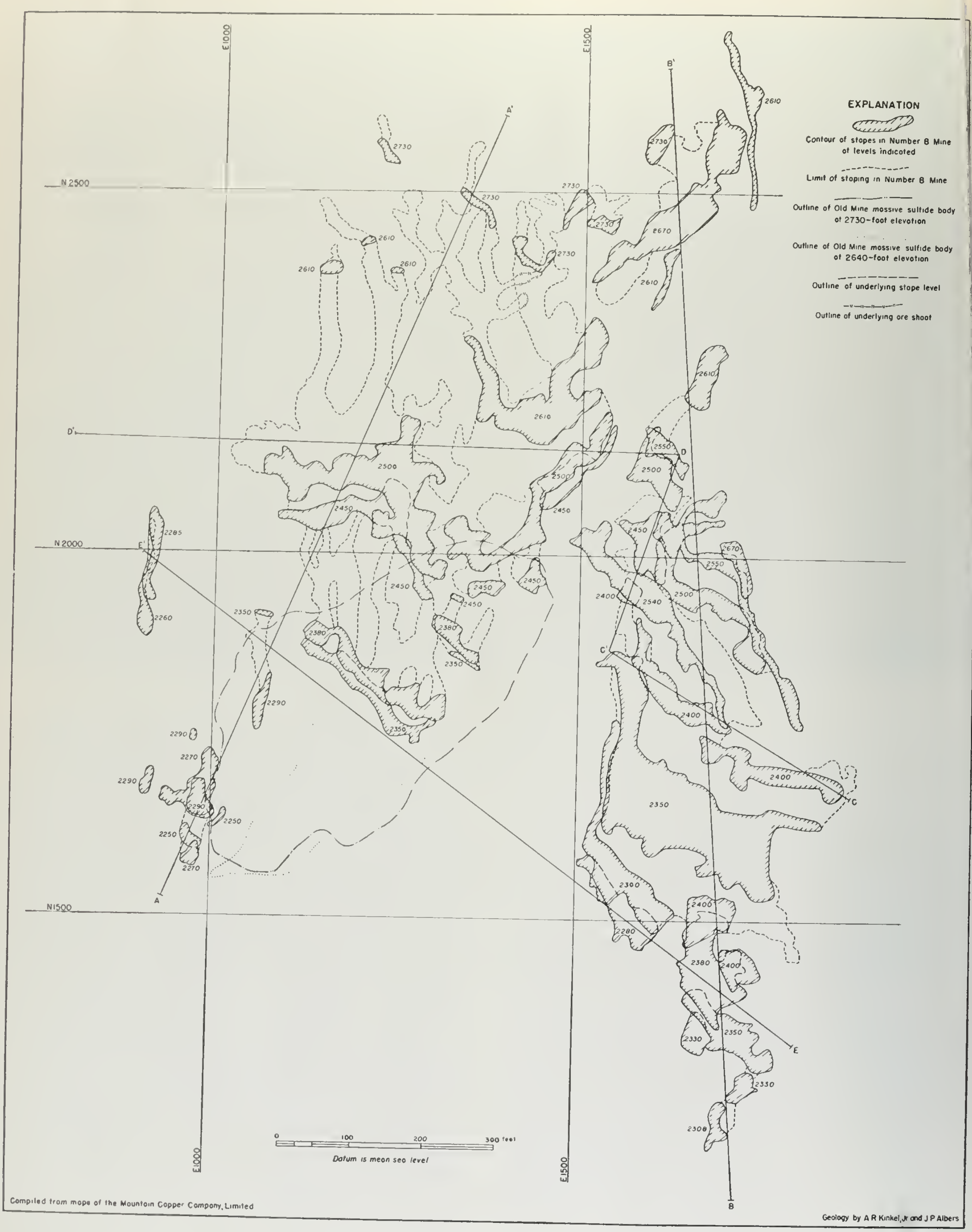


Figure 5. Plan of Number 8 mine ore bodies.

k Flat ore body. The Camden fault splits into several nds near its western end. The first displacement on Camden fault resulted in a dip-slip movement of about feet and occurred along the main Camden fault and fault that is now called the Camden North fault. The er was at that time a continuation of the main Cam- fault. Movement then occurred on the "J" fault, dis- ing the west portion of the Camden fault. Renewed ement along the main Camden fault displaced the " fault, forming a new break called the Camden South lt, which is a continuation of the main Camden fault t of the "J" fault.

The Camden North fault displaced the Richmond m the Brick Flat ore body and the Camden South lt apparently displaced the Brick Flat ore body from oxidized, up-dip extension of the Old Mine ore body. e displacement along the Camden fault is also shown the offset of the Balaklala rhyolite and Copley green- ne contact shown on sections 38 and 44, plate 4.

The Brick Flat ore body is explored only by rather dely spaced drill holes. It is apparently bounded on the rth and south edges by the two strands of the Camden ult, but different widths of ore in drill holes adjacent each other suggest that other faults are probably esent.

The "J" fault zone is well exposed in the northeast d of the Richmond-Complex ore body near the Scott ult, where it is accompanied by much more minor block ulting. Its location at the southwest end of the ore bodies also marked by block faulting and large inclusions of ste in the ore. The "J" fault has not been located with tainty in the center of the ore body, but several large ckensided surfaces are present in the massive sulfides, d the bottom of the ore in that vicinity shows block ulted inclusions of waste. It seems possible that the "J" ult in the central part of the Richmond-Complex ore dy is not a continuous fault, but has en echelon com- nents. The "J" fault in the central part of the ore dy has arbitrarily been drawn along a line between the eep portion, called the Complex ore body, and the flat rtion, called the Richmond ore body.

A strong fault zone occurs along the northwest side the Hornet ore body, and faulting is also reported in derground workings along its southeast side. The aline- nt of these faults with the Camden suggests that move- nt along them may be both pre- and post-mineral, as the Camden fault.

Many small post-mineral faults are found within the e bodies. These can best be seen along the edges of the e, where they may offset the contact as much as 50 feet. ey are marked by slickensided surfaces of massive sul- e ore, or by gouge. However, some gouge within the in sulfide mass is so continuous, and so far from the undaries of the ore, that it can only represent sheared mnants of unreplaced rock or pre-mineral fault gouge.

drothermal Alteration of the Wall Rocks

The rocks in the vicinity of the Iron Mountain mine ve been altered by sericitization, silification, chloriti- ion, pyritization, and by the formation of lavender or ite clay in the rocks. Field observations on hydro- ermal alteration associated with mineralization have t yet been supplemented by microscopic and chemical dies of the alteration zones.

Sericite is widespread and has no direct spatial relationship to metallization. It is true that sericitic wall rock is found at the ore boundaries as a gradation between gouge and the less sheared rock, but this sericite may be pre-ore and may not have been formed by the ore-depositing solutions. Large bodies of sericite schist are found far from known ore zones; in thin sections all the rhyolite contains some sericite.

Silicified rocks are found in all parts of the West Shasta copper-zinc district, but they occur most commonly along the mineral belts. Leached portions of pyritized and silicified rock show all gradations from rock with a few pyrite casts in a silica matrix to a porous silica sponge in which the silica occurred as septa between pyrite grains. Where pyritization was incomplete, relict quartz phenocrysts from the porphyritic rhyolite can be found in a rock almost entirely composed of secondary silica. Silicification in the mineralized zone is not always coextensive with pyritization, but pyritization of the massive sulfide type (i.e., anastomosing stringers and lenses of pyrite as contrasted with rock having isolated pyrite cubes) always occurs in silicified rock. It has not been possible to determine the age relationship between silicification and sulfide deposition. Silicification is believed to be mainly pre-ore, but some silica may have been added during ore deposition when the late quartz-chalcopyrite or quartz-carbonate veins were formed. In addition, some silica may have been derived from the rock that was replaced by massive sulfides, and stopped in transit by replacement of the wall rocks. Zones of strong silicification of the porphyritic rhyolite appear to indicate, in a broad way, the route of solutions in the mineral belt, but some of the silicification near ore deposits is related to widespread regional silicification.

Chloritization of the nonporphyritic rhyolite along seams and fractures occurs more commonly near ore bodies than remote from them. Little chloritization of the porphyritic rhyolite has been seen by the writers, but reports of chloritization accompanying chalcopyrite ore in the Number 8 mine indicate that this may occur locally.

Pyritization is more limited in distribution than any of the alterations previously described. It occurs in broad mineralized zones, but massive sulfide bodies are limited to a small part of the pyritized zones. No massive sulfide deposits are known to occur in the Iron Mountain area without the association of pyritized rock, but the pyritized bodies of rock may be small and not in immediate contact with the massive sulfide. On the other hand, large pyritized areas are found in this district that contain no known massive sulfide ores. The walls of the massive sulfide bodies at Iron Mountain are unmineralized, or only slightly mineralized except in the vicinity of the Old Mine ore body. Bodies of disseminated pyrite are found that parallel the sulfide deposits in the same mineralized zone, but disseminated pyrite does not occur as a halo around most of the massive sulfide bodies in the Iron Mountain mine.

Two types of claylike alteration products are closely associated with the ore bodies. One is the result of alteration of the porphyritic rhyolite to a soft, white claylike material with a chalky appearance. This alteration destroys original rock textures and schistosity, and although the product occurs principally as gouge along the walls of the ore or along faults, it also occurs as irregular zones in rock showing no evidence of movement. The other type of alteration product is a lavender, claylike material resulting from the alteration of porphyritic rhyolite. It is usually restricted to the porphyritic rhyolite that lies in or above the mineralization zone. This clay appears to be genetically related to massive sulfide bodies, but it is not found in immediate contact with them. The close spatial association between the massive sulfide ore and the white and lavender claylike alteration products at Iron Mountain suggests that the alteration products may be used to indicate areas worthy of prospecting in other parts of the district.

Summary of Features Controlling Ore Deposition

The broad ore controls believed to be responsible for the localization of the ore zone at Iron Mountain are the folds that acted as a guide for solution travel, the thick cover of shale that was present several hundred feet above the ore zone at the time of ore deposition, and the presence of main solution channels. More detailed controls that served to localize individual ore bodies are preferred layers in the flows and pyroclastics of the Balaklala rhyolite, fractures that served as solution channels, curvatures in strike and dip of bedding or schistosity, and pre-mineral fault gouges and shear zones.

Gently plunging folds, combined with a thick shale cover, are thought by the writers to be the main factors accounting for the distribution of ore on a broad scale in the entire West Shasta copper-zinc district. Solutions ascended along steep feeder channels and spread laterally along folded layers in the Balaklala rhyolite. It seems probable that ore bodies may have been formed at a considerable distance from a main feeder channel because of the guiding effect of flat-lying gently folded structural channels.

The ore in the West Shasta copper-zinc district occurs entirely in the Balaklala rhyolite and generally conforms in shape and distribution to rock structures. A fold in the bedding and schistosity around Iron Mountain peak conforms so closely to the distribution of ore in the quarry area that the mineralization seems obviously related to the fold. The Richmond-Complex ore body lies in a faulted syncline, as shown both by the shape of the Copley greenstone contact and by bedding in overlying tuffaceous material. Ore in the Number 8 mine is widest where changes in dip of the ore shoots occur, and its arcuate plan suggests control by plunging crumples in the schistosity.

The massive sulfide ore contains few recognizable remnants of unreplaced rock. Exposures showing incompletely replaced rock can be seen in some of the quarry benches, and these exposures suggest that the replacement favors massive porphyritic rhyolite with 2- to 4-millimeter quartz phenocrysts. Massive nonporphyritic rhyolite, flow-banded rhyolite, and rhyolitic volcanic breccia seem to be unfavorable host rocks in the Iron Mountain area, although ore occurs in volcanic breccia at other mines in the district. Some localities are found where a few relict phenocrysts are preserved in massive sulfide ore, indicating that the ore replaced porphyritic rhyolite; but the adjoining nonporphyritic rhyolite was not replaced.

Banded ore occurs in very subordinate amou the Iron Mountain mine, but very schistose rock found along the walls of massive sulfide bodies a nearby shear zones. There appears to be no reaso believing that the massive sulfide ore preferentiall placed more schistose parts of the rock.

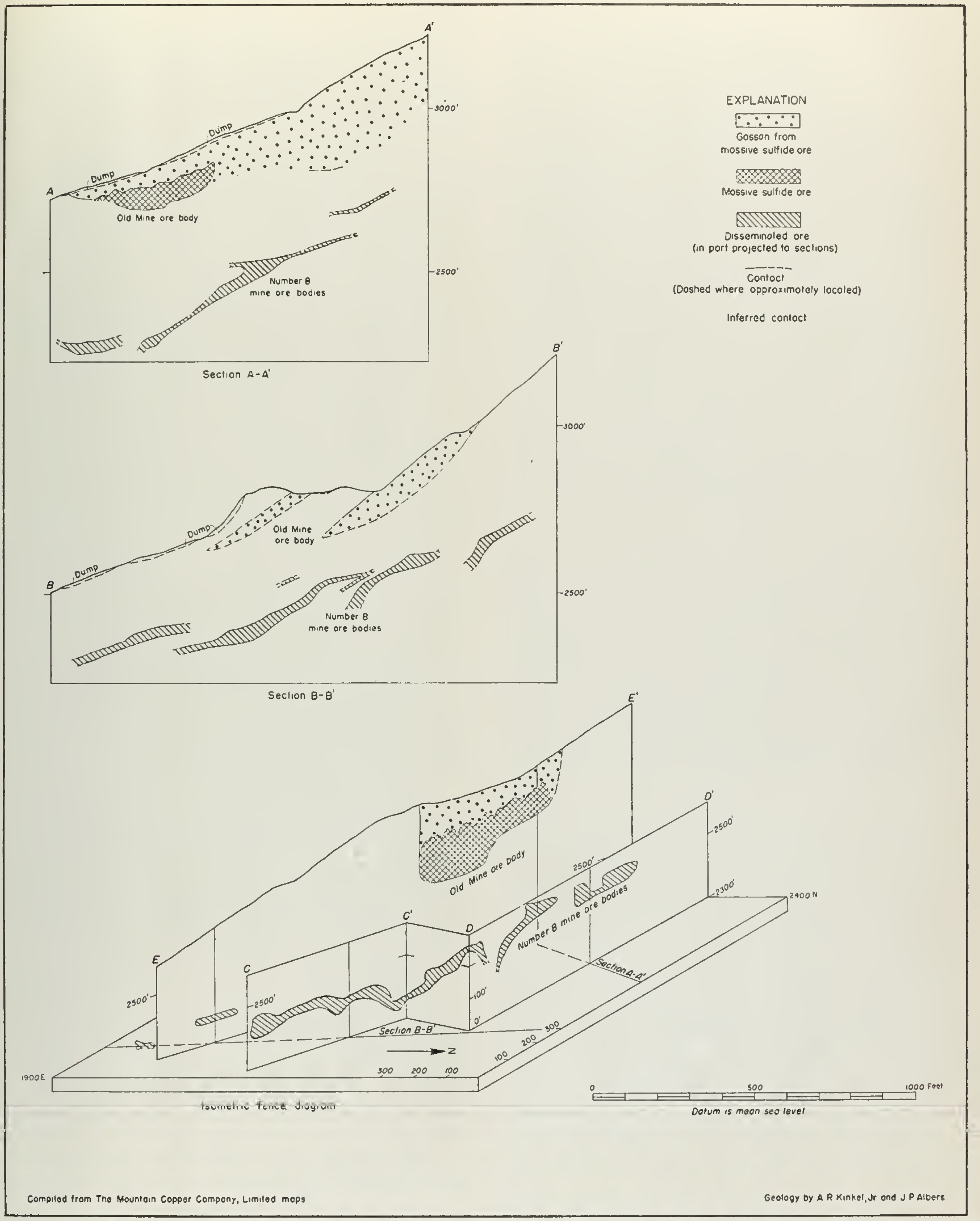
Solution channelways guided the mineral-bea solutions in detail. Where these channels were not fined by gouge, sulfide mineralized zones are widesp without sharp walls or complete replacement of the r but where gouges were present, the mineral-bearing tions were confined and effected a complete replace of the rock. Some bands of gouge extend into the o the form of long narrow sheets with too little moven of the ore bodies on either side of the gouge to acc for its formation as dragged wall rock. It seems prob that this gouge was present at the time of mineraliza but was not replaced. Although fault gouge occurs at contact of all the ore bodies, some of this gouge may h been formed by minor movement of the sulfide agai hydrothermally altered and softened rocks and does represent a large amount of movement or necessaril pre-mineral gouge.

The Camden and Sugar Loaf faults are pre-mine in age and may be the same fault, or they may be echelon to each other in the vicinity of the Hornet body. The presence of several bodies of gossan and mineralized zones along the strike of both faults exte ing to the northeast and southwest beyond the mapp area shows that mineral-bearing solutions were prese at many points along these faults.

The Camden and Sugar Loaf faults appear to ha been the channel for solutions forming the Hornet, Ric mond-Complex, and Brick Flat ore bodies, as well as t small areas of gossan shown along the eastern and weste extensions of these faults. The Camden fault probabl was not the solution channel for the formation of th Old Mine and Number 8 mine ore bodies because thes ore bodies dip away from the fault and because of th upward-branching ore pattern in the Number 8 min Unrecognized or concealed solution channels probabl exist south of these ore bodies. If this assumption is cor rect, the large syncline southeast of the Richmond-Com plex ore body should be a very favorable zone for or deposition.

Concentrations of chalcopyrite and sphalerite in the massive sulfide deposits, with the exception of those in the Old Mine ore body, all lie near the Camden fault, again marking this fault as a feeder. These concentrations are found in the Mattie ore body, the southeast side of the Complex ore body, and in the Richmond and Brick Flat ore bodies along the north branch of the Camden fault. The concentration of chalcopyrite in the bottom of some of the ore bodies adjoining the Camden fault also indicates that upward-moving, copper-bearing solutions were traveling along the fault.

The amount or direction of the pre-mineral movement on the Camden and Sugar Loaf faults is not known. It is believed to have been small because the ore bodies appear to have been continuous along one horizon before post-mineral faulting occurred.



Compiled from The Mountain Copper Company, Limited maps

Geology by A R Kinkel, Jr and J P Albers

FIGURE 6. Sections of Number 8 mine and Old Mine ore bodies. Location of sections is shown on Figure 5.

Oxidation and Enrichment

Types of Gossan. Small relict nodules of massive pyrite have been found in gossan within 10 feet of the surface in the upper part of the quarry. However, the high relief and broken, porous character of the ground allows more or less complete leaching and oxidation to the depth of several hundred feet over most of the mineral zone. The deepest oxidation extended down along the footwall of the Camden fault, where oxidized material is found locally at a depth of 400 feet below the surface.

Two types of gossan have been distinguished in the mapped area. One of these was derived from disseminated pyrite and ranges from rock with scattered pyrite casts to rock and silica sponge in which the rock structure is preserved but which may have contained 50 percent or more pyrite. Rock that is estimated to have contained less than 10 percent of pyrite is not shown as gossan on the map. The second type of gossan is that derived from massive sulfide ore. This gossan contains no discernible traces of the original rock structure. It consists of limonite in the form of earthy, spongy, and porous masses with quartz septa, or of limonite crusts and dense limonite, or a breccia of angular fragments of rock and vein quartz embedded in limonite. Relict nodules of massive pyrite are found in the dense limonite and more rarely in the porous or earthy limonite but not in the breccia.

Most of the massive sulfide ore contained too little quartz to form a quartz skeleton upon removal of the pyrite. The normal gossan from the oxidation of the massive sulfide ore is a spongelike aggregate of yellow, red, brown, or iridescent limonite, with thin quartz septa forming the framework of the sponge. This quartz appears to be secondary, as the quartz septa are not seen in unoxidized ore. Soft and earthy, or dense limonite occurs in the sponge, and there is some transported limonite with irregular crusts and botryoidal forms. Large caves lined with iridescent botryoidal limonite crusts and containing stalactites of limonite several feet in diameter have been found in the gossan derived from massive sulfide ore.

In gossan derived from pyritized rock, bands of the rock parallel to the schistosity are locally completely replaced by silica and pyrite in ribbonlike structures. The ribbons usually contain more than 50 percent silica and tend to stand out as resistant ribs of silica sponge on weathered surfaces. Material between the mineralized bands contains less silica and pyrite, or it may be entirely unmineralized.

Relict nodules of massive pyrite in gossan have very sharp boundaries, with a band of white silica sponge surrounding the sulfide. In some specimens the band of white silica sponge is only a thin seam, whereas in others it is as much as an inch thick. Still other specimens show only a nodule of spongy silica, residual after sulfide ore, surrounded by dense limonite. Solutions appear to have dissolved the iron and transported it a distance equal to the width of the silica sponge border zone before redepositing it as dense limonite. The zone of dense limonite was apparently being altered to porous limonite sponge along its outer borders as it encroached on the sulfides. The band of dense limonite and the band of limonite-free silica sponge maintain an approximately constant width surrounding both large and small nodules of sulfide, and both are believed to travel into the fresh sulfides as oxidat progresses.

No correlation is possible between the types of li nite found in the gossan and the copper content of massive sulfide bodies, as nothing is known about primary mineralogy of the massive sulfide bodies th have been entirely converted to gossan. No outcrop of t copper-bearing disseminated ore is known.

The decrease in volume must have been large whe gossan was formed from massive sulfide ore. The presen of angular rock fragments 50 feet or more from the wa of the gossan in collapse breccias indicates a considerab collapse of the walls. It is probable that some of the go sans seen at the surface represent only a small part the width of the massive sulfide ore that was present befo oxidation and consequent collapse of the walls. Th schistose character of much of the wall rock would allo a considerable expansion toward the gossan without a obvious appearance of collapse in the outcrop.

Supergene Enrichment. The Old Mine ore body the only body of sulfide ore in the Iron Mountain min that contained supergene copper minerals. The other or bodies in the mine area were either completely converte to gossan, or lie below the zone of oxidation. No concen tration of supergene copper minerals is known in th small gossan area over the north end of the Hornet or body, probably because this ore contained very low value in copper. No copper oxides or copper carbonates ar present in the gossan. The gossan over the Old Mine or body contained less than 0.25 percent copper and no zinc, but a thin enriched zone in the sulfides along the irregular bottom of the gossan had a high content of copper and an exceptionally high content of silver. This zone is reported to have been several feet in thickness and to have consisted of black sandy sulfides that graded downward into massive sulfide ore. No records remain of the assays in this zone, but considerable silver ore was mined from the enriched layer.

A few specimens of ore from the Old Mine ore body have been collected from dumps in the vicinity of the Old Mine. They are fine-grained massive sulfide ore that have a bluish rather than brassy color. Thin seams of chalcocite can be seen in the hand specimens, and other secondary copper minerals may be present. The following table, compiled by Seager[18] indicates the amount of copper enrichment in the upper part of the Old Mine ore body.

Elevation (feet)	*Average copper content (percent)*
above 2741 (gossan)	0.25
2741	10.0
2732	10.0
2720	8.0
2710	8.0
2682	6.0
2614	6.0
2601	3.5

The average gold content of the gossan over the Old Mine ore body is 0.073 ounce per ton and that of the massive sulfide ore below the gossan is 0.04 ounce per ton. This is a residual enrichment caused by leaching and oxidation of the sulfide minerals. The average weight of the

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[18] Unpublished report.

san is 165 pounds per cubic foot and that of the sulfide
is 275 pounds per cubic foot.

Silver and zinc have been removed from the gossan
r the Old Mine ore body, and although the silver ap-
ars to have been precipitated at the contact between
gossan and the sulfides, no bodies of secondary zinc
nerals have been found.

e of Mineralization

Pyrite seams and quartz veins containing pyrite and
alcopyrite have been found in all the rocks mapped in
West Shasta copper-zinc district, but little informa-
n exists that would indicate when the sulfide minerals
re emplaced. However, the main body of biotite-quartz
orite has been only slightly mineralized and the min-
als are restricted to a few quartz-galena-gold-silver veins
th some chalcopyrite in an area about 12 miles south
Iron Mountain. It seems doubtful that these veins in
e biotite-quartz diorite are genetically related to the
assive pyrite type of mineralization. Sheared portions of
e albite granite as well as the Devonian and Mississip-
an sediments contain minor amounts of pyrite. It seems
ssible that the massive base-metal type deposits re-
laced the Balaklala before the biotite-quartz diorite was
nplaced but after the albite granite was emplaced. The
massive sulfide deposits may be late Jurassic in age, but no direct evidence has been found to connect the base metal deposits genetically with any of the intrusive rocks.

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OLAF P. JENKINS, CHIEF

STATE OF CALIFORNIA
DEPARTMENT OF NATURAL RESOURCES

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

SPECIAL REPORT 14
PLATE 1

Topography by the Mountain Copper Company, Limited, with additions by A R Kinkel, Jr., and J P Albers
Co-ordinates and numbered sections are those used by the Mountain Copper Company, Limited

Geology by A R Kinkel, Jr., and J P Albers

EXPLANATION

Recent — QUATERNARY
Qls — Landslide

JURASSIC (?)
agr — Albite granite

DEVONIAN — Balaklala rhyolite

Extrusive	Intrusive	
Dbx	Dbn	Rhyolite
Dbx₁	Dbn₁	Porphyritic rhyolite Small (0-2mm) phenocrysts
Dbx₂	Dbn₂	Porphyritic rhyolite Medium (2-4mm) phenocrysts
Dbx₃	Dbn₃	Porphyritic rhyolite Large (over 4mm) phenocrysts

Dbb — Volcanic breccia and tuff
Dbm — Mafic flows
Balaklala rhyolite

DEVONIAN (?)
Dcg — Copley greenstone

mh — Magnetite-hematite rock

Gossan from massive sulfide ore

Gossan from disseminated sulfides
(Rock that contained 10 to 75 percent sulfides)

Contact, showing dip
(Dashed where approximately located)

Indefinite contact
(Includes inferred contacts)

Fault, showing dip
(Dashed where approximately located
U, upthrown side; D, downthrown side)

Vertical fault

Probable fault

Anticline, showing crest line
(Approximately located)

Syncline, showing position of trough
(Approximately located)

Strike and dip of beds

Strike of vertical beds

Strike and dip of foliation

Strike of vertical foliation

Scarp of caving ground

Scarp of open cut and bench

Narrow gauge railroad
(Part cable car)

Adit

Caved adit

Dump

Approximate property line

Projection of outline of underground ore bodies

GEOLOGIC MAP OF THE IRON MOUNTAIN MINE AREA, SHASTA COUNTY, CALIFORNIA

0 500 1000 Feet
Contour interval 25 feet
Datum is mean sea level

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PLATE 2

IRON MOUNTAIN MINE, PLAN AND LONGITUDINAL SECTION OF ORE BODIES

0 500 1000 Feet
Datum is mean sea level

Compiled from maps of The Mountain Copper Company, Limited

Geology by A R Kinkel, Jr and J P Albers

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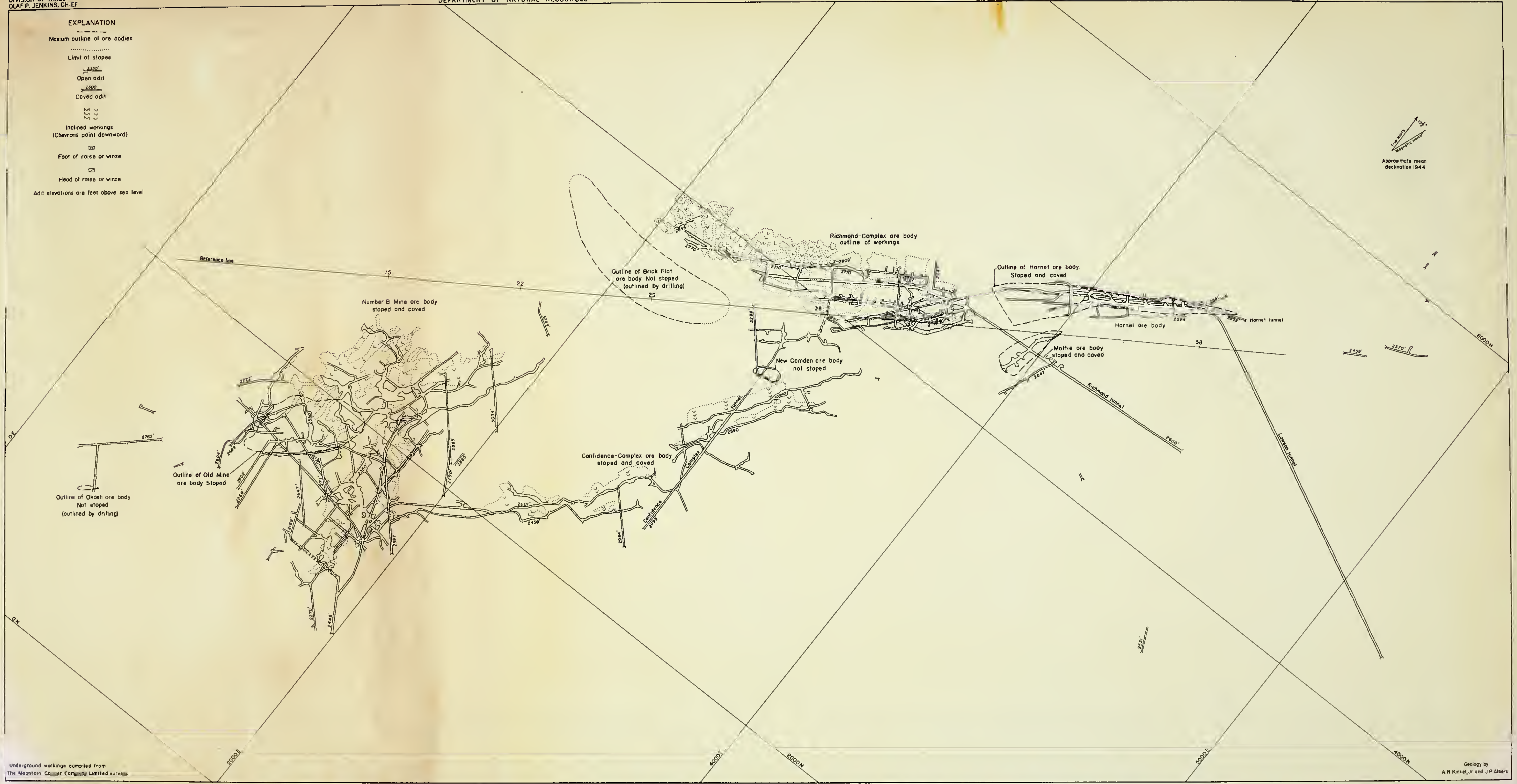
PLATE 3



Underground workings compiled from
The Mountain Copper Company Limited surveys

Geology by
A. R. Kinkel, Jr. and J. P. Albers

IRON MOUNTAIN MINE, PLAN OF UNDERGROUND WORKINGS

Datum is mean sea level

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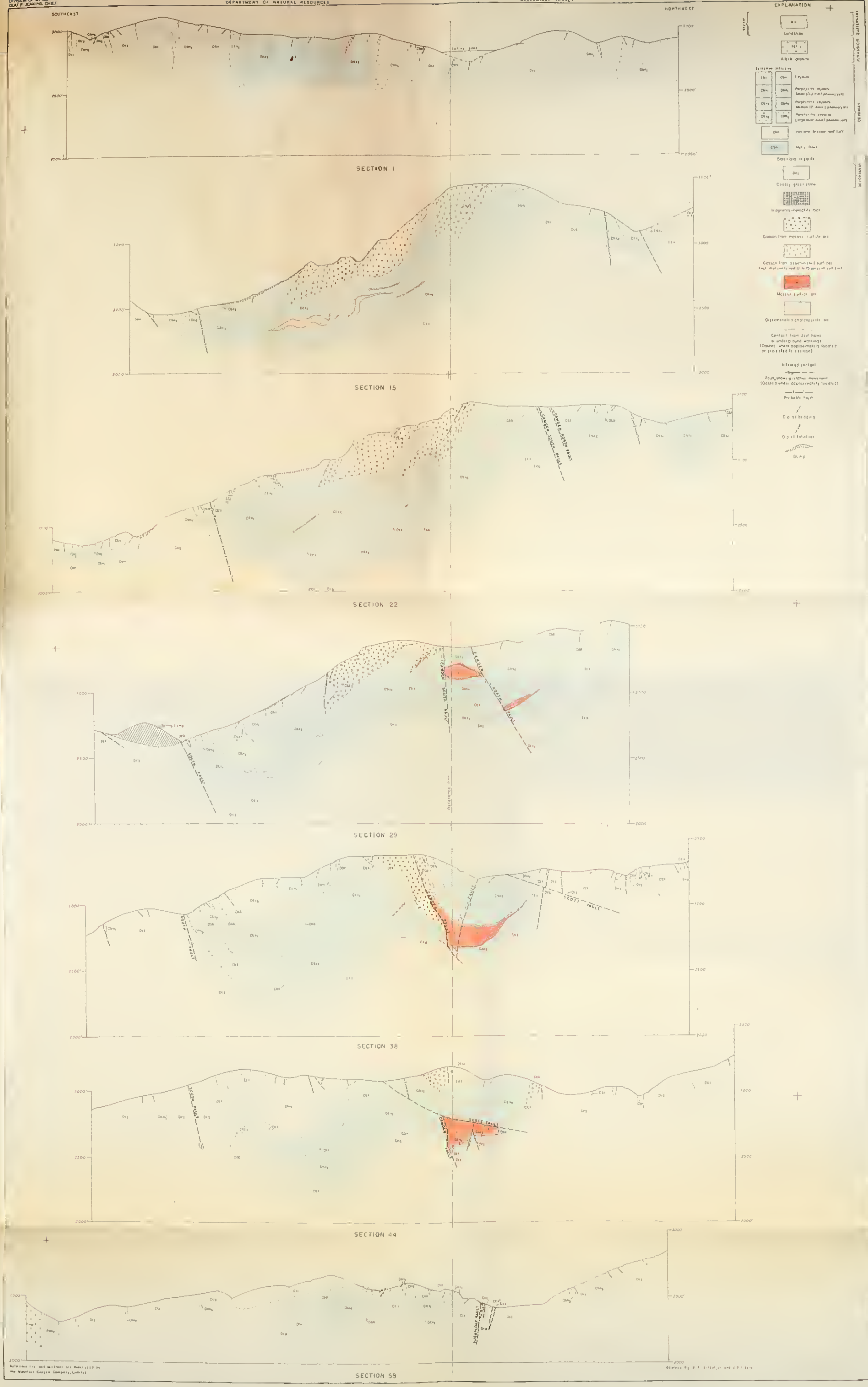
PLATE 4



GEOLOGIC CROSS SECTIONS, IRON MOUNTAIN AREA

0 500 1000 feet

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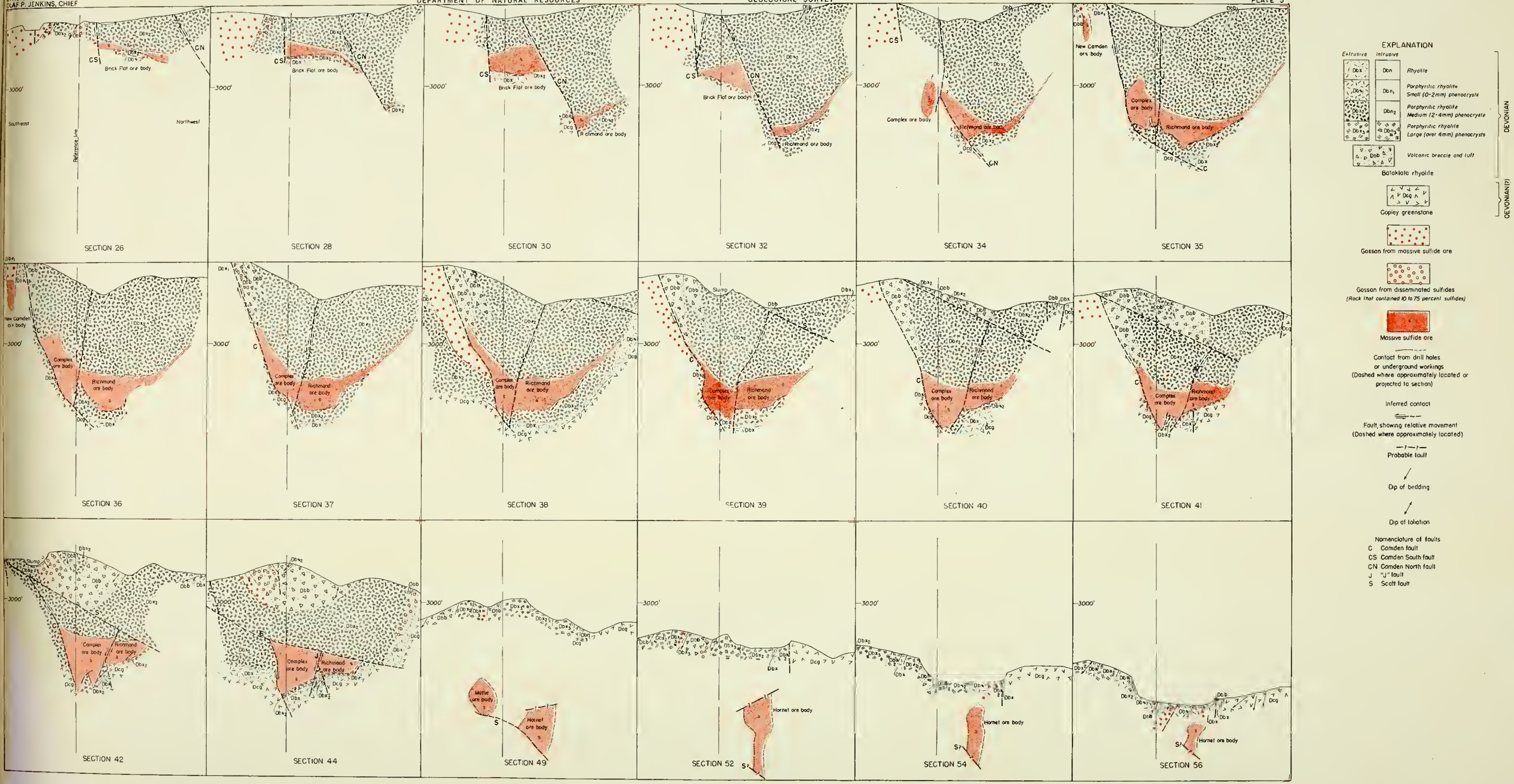
SPECIAL REPORT 14
PLATE 5



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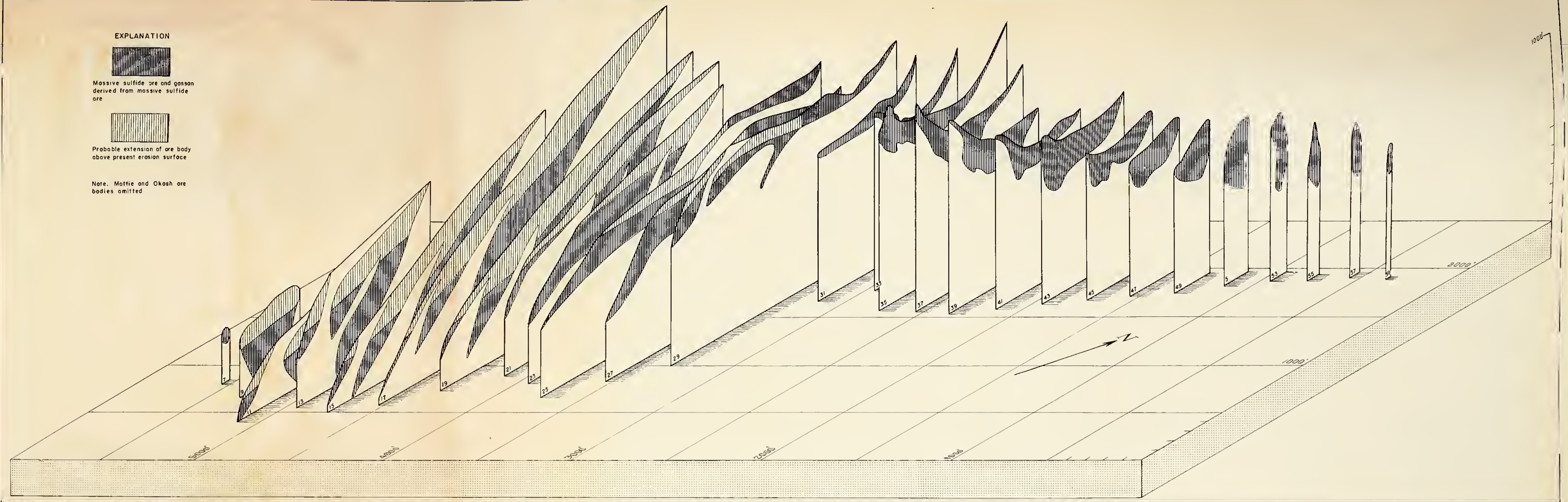
CROSS SECTIONS OF ORE BODIES

0 500 1000 Feet

Datum is mean sea level



RESTORATION OF THE IRON MOUNTAIN ORE BODY BEFORE FAULTING AND EROSION